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EARTH SCIENCES
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1 OF 1

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USSR REPORT

EARTH SCIENCES

(FOUO 9/80)

CONTENTS

METEOROLOGY

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MONOGRAPH ON PHYSICAL PRINCIPLES FOR MODIFICATION OF ATMOSPHERIC PROCESSES

Leningrad FIZICHESKIYE OSNOVY VOZDEYSTVIYA NA ATMOSFERNYYE PROTSESSY (Physical Principles for the Modification of Atmospheric Processes) in Russian 1978 signed to press 17 Nov 78, pp 2-4

[Annotation and Table of Contents from book by L. G. Kachurin, Gidrometeoizdat, 3,500 copies, 456 pages]

[Text] Annotation

This book by Professor L. G. Kachurin is devoted to the physical principles for the modification of atmospheric processes. It examines the theory of phase transitions. A thermodynamic model of natural and artificially created convective clouds is formulated. The possibilities of stimulation of convection, inducement of precipitation, contending with hail, scattering of clouds and fogs are investigated. The principles for the modification of electric processes in the atmosphere and hurricanes are studied. Intentional and inadvertent disruptions of equilibrium in the ionosphere and ozonosphere are considered. The book is a substantially revised and supplemented edition of the instructional text published in 1973. The monograph is intended for students and graduate students at universities and hydrometeorological institutes. It can be used for specialists in the field of atmospheric physics, preservation of the environment, aviation, cosmonautics, sea and land transportation, etc.

TABLE OF CONTENTS Page

[12-5303]

5303
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MODELS USED IN INVESTIGATION OF ATMOSPHERE AND CLIMATIC CHANGE

Moscow FIZIKA ATMOSFERY I PROBLEMAKLIMATA (Atmospheric Physics and the Climate Problem) in Russian 1980 signed to press 7 Feb 80 pp 2-7, 258

[Annotation, Table of Contents, and Foreword from book edited by G. S. Golitsyn and A. M. Yaglom, Izdatel'stvo "Nauka", 1,200 copies, 262 pages]

[Text] Annotation

In recent years the problem of climate and its changes has been attracting the broad attention of international scientific society and the governments of many countries. The world economy, which is growing more complex, is becoming increasingly more dependent on climatic conditions, and there are indications that man's activity itself is beginning to have an influence upon climate and its changes. The atmosphere is one of the dominant and most mobile elements within this problem. Investigation of the physics of atmospheric processes, creation of models of the atmosphere viewed as a nonlinear dynamic system, to include low-parameter models, study of the interaction between the atmosphere and the underlying surface--oceans and land, and study of the optic and radiating properties of aerosol influencing the atmosphere's thermal cycles are all important to gaining a deeper understanding of the physics and dynamics of the atmosphere *per se*; concurrently, such studies can also serve as a basis for creating a theory of general circulation and climate theory.

This book will be useful to specialists in atmospheric physics, meteorology, climatology, oceanology, and associated areas, as well as to graduate students and senior students of the appropriate specialties in universities and other educational institutions.

Table of Contents

Foreword

In recent years the problem of climate and its changes has been transforming more and more from a purely scientific problem into one attracting the persistent attention of the broadest circles of society, the governments of many states, and authoritative international organizations. The greater frequency of droughts in different regions of the world and the somewhat abnormally cold and snowy winters in Europe and the USA have made the questions of periennial variations in climate and the trends of its evolution very troubling. Swift development of power engineering and a dramatic increase in anthropogenic contamination of the environment are making the situation even more complex, and it is apparent that in the foreseeable future, they may make a noticeable contribution to changes in climatic indicators.

The problem of explaining climate is unusually complex, since we are talking about laws governing an enormous system with a very large number of degrees of freedom including the ocean, the atmosphere, and the biosphere. Therefore its solution would require the coordinated efforts of scientists in many countries representing different specialties. The overall direction of the research, its methodology, and its basic content are being worked on jointly by specialists in atmospheric physics, oceanology, glaciology, and climatology. The first major undertaking of this sort was a special international conference of the PIGAP (Program of Investigation of Global Atmospheric Processes) having the purpose of writing up a program to study the physical principles of climate and to model it; this conference was convened in August 1974 near Stockholm. The program written at this conference was later translated into Russian.* An all-union conference was held a year later to prepare a draft program of climatic studies in the USSR.**

The World Climate Conference was held in Geneva in February 1979. It adopted an appeal to all nations, in which the importance of the problem of climate and its changes to the most varied aspects of the life of mankind was emphasized, as was the need for broad international cooperation in research on this problem (see METEOROLOGIYA I GIDROLOGIYA, No 87, 1979).

The atmosphere doubtlessly plays one of the most important roles in the climate generating system. Weather forms within the atmosphere, and local changes in weather are directly associated with the instability of atmospheric circulation; the atmosphere is the principal carrier of heat from the tropics into more-northerly regions; the atmosphere exchanges heat, moisture, and momentum with the underlying surface, insuring constant turnover of moisture and transformation of the Sun's thermal energy into the kinetic energy of wind. The computation and modeling of all of these processes make up one of the most significant parts of the program to model climate and its changes. The most important and immediate stage in this sort of research is development of simplified mathematical models of climate and models of general circulation of the atmosphere, which plays an important climate-forming role. In particular the documents cited above suggest utilizing an entire hierarchy of climate models, beginning with the simplest models based only on an averaged zonal equation of the energy budget on the Earth's surface, and ending with complex models adapted to the most powerful modern computers, models which numerically integrate the multilevel equations describing joint circulation of the atmosphere and ocean with a consideration for the hydrologic cycle, the annual course of insolation, and so on.

This collection is devoted to research on some of the questions mentioned above. The papers contained herein reflect all of the basic directions of research being conducted in the institute responsible for this problem, with the exception of just the research on general circulation and climate of the Earth and other planets with the help of the methods of similitude and dimensionality, a review of which could be found in a number of works.***

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* "Fizicheskiye osnovy teorii klimata i yego modelirovaniya" [Physical Principles of the Theory of Climate, and Its Modeling], Moscow, Gidrometeoizdat, 1977, 272 pp.

** "Fizicheskiye osnovy klimata i yego izmeneniy. Natsional'naya programma SSR PIGAP--klimat" [The Physical Principles of Climate and Its Changes. The USSR National Program PIGAP--Climate], Soviet PIGAP Commission, Interdepartmental Geophysical Committee, USSR Academy of Sciences Presidium, Obninsk, VNIIGMI-MTsD, 1977, 148 pp.

*** Golitsyn, G. S., "The Theory of Similitude in Soviet Works on Geophysical Hydrodynamics," IZV. AN SSSR. FAO, Vol 13, No 11, 1977, pp 1132-1149; "Vvedeniye v dinamiku planetnykh atmosfer" [Introduction to the Dynamics of Planetary Atmospheres], Leningrad, Gidrometeoizdat, 1973, 104 pp.

The collection begins with a paper by V. K. Petukhov, "A Zonal Climatic Model of Heat and Moisture Exchange in the Atmosphere Above the Ocean." According to the modern classification, this model may be placed in the class of dynamic-statistical models: When given in its expanded form, it contains a dependence on time and latitude, but the form of many of the dependencies on altitude is previously given. A large number of new methods of parametric expression of meridional and vertical transfers of momentum, heat, and moisture are proposed in the paper. The model has not been built in its entirety yet, but a number of its simplified variants provide information on the distribution of meteorological elements close to their mean climatic values.

The article by A. S. Ginzburg and Ye. M. Feygel'son, "Parametric Expression of Radiant Heat Exchange in Models of General Atmospheric Circulation", offers a review of the methods and concrete procedures of parametric expression of radiation in the ultraviolet, visible, and infrared ranges, generated by solar and thermal emissions depending on temperature and on the gas and aerosol composition of the atmosphere. The article contains concrete recommendations for models exhibiting different degrees of complexity.

Then follow three papers on so-called low-parameter models of the atmosphere and other hydrodynamic systems. The concept of hydrodynamic systems introduced by A. M. Obukhov in 1969 played an important role in development of this direction.* A hydrodynamic system possesses the same integral invariants and the same nonlinearity that we see in real hydrodynamic equations, except that they are characterized only by a finite and, usually, a small number of degrees of freedom; a hydrodynamic system correctly describes many aspects of real fluid flows and, in particular, major atmospheric movements. The first work of this group is the paper by M. B. Galin, "Investigation of General Atmospheric Circulation on the Basis of a Twelve-Component Model". Applying the Bubnov-Galerkin method to the spectral form of hydrodynamic equations, the author proposes a two-level nonlinear baroclinity model describing interaction of waves with a zonal flow. Questions associated with evolution of a zonal current under the influence of nonlinear interactions with planetary waves are examined, as are their relationship to linear theories of zonal current stability in the presence of energy sources and discharges. The energy cycle of these interactions is analyzed, and it is found to be close to the cycle of energy transformations in the real atmosphere.

* Obukhov, A. M., "Integral Invariants in Hydrodynamic Systems," DOKL. AN SSSR, Vol 184, No 2, 1969, pp 309-312; See also Dolzhanskiy, F. V., Klyatskin, V. I., Obukhov, A. M., and Chusov, M. A., "Nelineynyye sistemy gidrodinamicheskogo tipa" [Nonlinear Hydrodynamic Systems], Moscow, Izd-vo "Nauka", 1974, 160 pp.

The article "An Extremely Simple Nonlinear Model of Convection and Its Geophysical Application" by F. B. Dolzhanskiy and L. A. Pleshanova is a good example of research based on the hydrodynamic system concept. It examines a low-parametric model of convective currents arising under the influence of nonuniform heating of the system and its rotation as a whole. Many characteristics of the behavior of the system under analysis here, particularly its energy cycle and the nature of arising instabilities, are similar to those of large-scale atmospheric circulation.

The article "Hydrodynamic Models and the Change-Over Phenomenon" by A. B. Gluzhovskiy, V. I. Klyatskin, and A. M. Obukhov studies an issue important to the theory of climate and general circulation--the possible existence, in the same external conditions, of two or several patterns of flow, and the possibilities for transfer from one pattern to another. This investigation was performed with a simple hydrodynamic system with a very small number of degrees of freedom as the example.

The article "One Stochastic Model Associated With the Problem of the Predictability of Climatic Processes" by M. I. Fortus is devoted to problems having a direct bearing on statistical prediction of climatic characteristics. Such predictions are meaningful in relation to time periods in regard to which dynamic prediction becomes useless due to growth in errors generated by inaccuracies in the initial data, by simplifications at the basis of the model employed, by ignorance of the detailed physics of processes forming climate, and so on. Such prediction relies upon the use of information on the spectrums of climatic fluctuations, information that came into being in recent years. In this case, however, it is very important to establish for precisely which climatic characteristics the error of the statistical prediction rises relatively slowly in response to an increase in the prediction time, and for which it grows so quickly as to deprive a prediction of this sort of its practical value. The paper by M. I. Fortus seeks, in the best possible fashion, predictible characteristics for some special classes of random processes, the spectrums of which extend upward from the low frequency range and possess sharp, widely scattered peaks--that is, a number of properties inherent to real spectrums of climatic characteristics.

Two of the collection's articles are devoted to research on the boundary layer of the atmosphere. Through the boundary layer, the atmosphere interacts with the underlying surface, and therefore parametric expression of processes occurring in this layer (mainly vertical transfer of heat, moisture, and momentum) is a very important part of work on a general circulation model and on any climate models of any sort of detail. The work by V. P. Kuzharets, L. R. Tsvang, and A. M. Yaglom, "The Relationship Between Turbulence Characteristics of the Surface Layer and Boundary Layer of the Atmosphere", reviews the results of measuring the characteristics of turbulent transfer in the surface layer and in the entire planetary boundary layer. The authors reveal a number of dependencies between vertical transfer in the boundary layer and the characteristics of the atmosphere's boundary layer; these dependencies, when applied to measurements made near to the surface of the Earth, permit certain conclusions on turbulent processes in the boundary layer. A new method for determining the height of the boundary layer, important to parametric expression of the interaction between atmosphere and underlying surface, is proposed incidentally.

The article "Universal Functions for Atmospheric Turbulence Above the Sea" by A. S. Aliyev, S. L. Zubkovskiy, and L. R. Tsvang presents the results of numerous measurements, made from a motionless platform on the Caspian Sea 20 km from shore, of the characteristics of turbulence in the layer of atmosphere overlying the water. These measurements demonstrate that universal functions describing, within the framework of the well known Monin-Obukhov theory of similitude, the dependence between the height of the mean temperature and dispersions of pulsations in the three components of wind speed and temperature differ little at a given point of observation from functions obtained from observations made in the boundary layer of the atmosphere.* As far as the dimensionless phasal velocity of waves upon which, as it is often thought, universal functions of induced turbulence should also depend significantly, is concerned, it is found to be closely correlated with atmospheric stratification.

The collection ends with an article by G. V. Rozenberg, G. I. Gorchakov, Yu. S. Georgiyevskiy, and Yu. S. Lyubovtseva, "Optic Parameters of Atmospheric Aerosol". It proposes a stratification model and a set of optic aerosol parameters on the basis of a generalization of the results of statistically analyzing data covering many years of integrated research on atmospheric aerosol. This model is highly valuable to the modeling of climate and general circulation, inasmuch as aerosol is one of the most important and presently least studied optically active components of the atmosphere.

The authors of this collection--specialists in mathematical physics--attempted to apply the techniques of established subdivisions of atmospheric physics to the complex problem of climate, and to sketch the new methods and approaches for solving this problem. We can hope that some of these proposals will enjoy development, and that they will be utilized in the future with greater concreteness and detail.

We hope that this collection will be found useful to a broad range of specialists in atmospheric physics and in meteorology in general, moreover not only to those who are directly associated with the problem of climate and its changes, but also to many persons dealing with associated scientific problems.

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* For data on the surface layer of the atmosphere, see for example the following articles by A. M. Yaglom: Yaglom, A. M., "Data on the Characteristics of Turbulence in the Surface Layer of the Atmosphere," IZV. AN SSSR. FAO, Vol 10, No 6, 1974, pp 566-586; Yaglom, A. M., "Comments on Wind and Temperature Flux-Profile Relationships," BOUNDARY-LAYER METEOR., Vol 11, No 1, 1977, pp 89-102.

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MODEL OF INTERMITTENCE OF OCEAN TURBULENCE

Moscow OKEANOLOGIYA in Russian Vol 20, No 3, 1980 pp 381-387

[Article by M. M. Lyubimtsev, Institute of Oceanology imeni P. P. Shirshov USSR Academy of Sciences, submitted for publication 13 January 1978, resubmitted after correction 17 January 1980]

[Text]

Abstract: The author examines a model of a one-dimensional section of the field of intermittent turbulence. Within the framework of the model it was possible to ascertain the influence of intermittence parameters on some statistical characteristics of small-scale turbulence. It is shown that the semi-invariants of the interm. tent process and also the mean rate of dissipation of turbulent energy are proportional to the mean intermittence coefficient; the dropoff of the correlation and spectral functions with an increase in the argument is essentially dependent on the distribution of probabilities of the size of the "turbulent spots."

An important property of turbulence is its intermittence, that is, the nonuniformity of the distribution of turbulent movements in space and time. We should differentiate several types of intermittence. By the term "internal intermittence" we will mean the nonuniform distribution of the energy of movements in a well-developed stationary turbulent flow. Its cause is the random character of the fragmentation of turbulent inhomogeneities. There are mathematical models of such intermittence [5-7, 9]. A result of internal intermittence is fluctuations of the field of dissipation of turbulent energy, the investigation of which is the subject of the fundamental studies [10-11].

External intermittence is a nonuniformity in the distribution of the ene. of turbulence in a flow with "spots" of turbulent fluid developing in it sporadically. The flow outside such "spots" is hydrodynamically stable and the current here is laminar. A flow with such intermittence can be statistically stationary. The phenomenon of external intermittence of turbulence in the ocean can be observed, in particular, between the turbulent and nonturbulent regions at the lower boundary of the upper mixed layer and at the upper boundary of the bottom layer. In the main thickness of the ocean this is the intermittence of turbulent "spots," arising, for example, due to the hydrodynamic instability of the internal gravitational waves in the shear flow.

Evidently there can be still another type of intermittence -- the intermittence of turbulence in the last stage of its degeneration, when it is possible to observe a field of randomly distributed "spots" of slightly turbulent fluid. Such intermittence is probably associated with internal intermittence, but differs from it considerably because it is essentially nonstationary.

In the experimental investigation of turbulence in the ocean the records of the signals of the measured parameters (fluctuations of velocity, temperature, etc.) by low-inertia sensors have the form of alternating pulses (of different shape and width), separated by noise intervals of irregular duration. Such a pulse modulation of signals is also a result of external intermittence of turbulence. For describing this type of signals in this study we propose an elementary model within whose framework we examine the influence of the parameters of external intermittence on some statistical characteristics of small-scale turbulence (henceforth, for the sake of brevity in exposition, the word "external" will be omitted in reference to intermittence).

Now we will examine the random process $\xi(t)$, representing the product of the stationary random process u(t) (with the mean value $\langle u(t)\rangle = 0$) and the pulsed process I(t) with the random times of development t_i and the duration θ_i of the i-th pulse (i = 1, 2,...) of a unit amplitude. The I(t) process can be represented in the form $I(t) = \sum I_i(t)$, where $I_i(t)$ is the i-th pulse situated randomly on the time axis. Then the $\xi(t)$ process can be written in the form

$$\xi(t) = \sum_i u_i(t)\, I\left(\frac{t-t_i}{\theta_i}\right) \equiv \sum_i F_i(t). \tag{1}$$

Here $I(x) = \chi(x) - \chi(x-1)$, $\chi(x)$ is a unit Heaviside function. The argument $x = (t - t_i)/\theta_i$ was selected in such a way that with a change in t from t_i to $t_i + \theta_i$, that is, in the limits of the i-th pulse, the x value changes from 0 to 1; I(x) = 1. Outside the pulses I(x) = 0. We will assume that the $\xi(t)$ process is a model of the one-dimensional section of the turbulence field.

In order to compute the statistical characteristics of the $\xi(t)$ process it is necessary to introduce a number of hypotheses concerning its stochastic structure: 1. The probability that in the time interval T exactly n pulses will develop is dependent on T, but not on the position of this interval on the time axis, that is, a homogeneity of the pulsed process is assumed. 2. The number of pulses developing in nonintersecting time intervals represents independent random values, that is, an "aftereffect" is absent. 3. The probability that more than one pulse will develop in a small time interval dt is a value of an order less than dt, that is, when $dt \to 0$ this probability is equal to o(dt). Physically this means the impossibility of the development of two pulses simultaneously (these hypotheses were proposed by A. Ya. Khinchin in an investigation of the flow of random events and in this formulation were cited in [2]). 4. All $u_i(t)$, t_i and θ_i are statistically independent and their distribution of probabilities is not dependent on the number of the pulse.

It can be demonstrated [2] that the first three hypotheses are adequate in order that the probability $P_T(n)$ that n pulses will appear during the time T will be described by a Poisson distribution:

$$P_T(n) = \frac{(\lambda T)^n}{n!} e^{-\lambda T}, \tag{2}$$

where $\lambda = \langle n \rangle / T$ is the mean number of pulses developing in a unit time. In particular, it follows from the distribution (2) that the density of the distribution of probabilities $W_i(t)$ of the moments of development of the pulses t_i is constant and equal to λ. In actuality, the probability that the pulse develops in the small interval [t, t + dt] is $W_t(t)dt$. But this same probability can be written using the distribution (2): $P_{dt}(1) = \lambda dt \exp(-\lambda dt) = \lambda dt + o(dt)$, that is, with an accuracy to a value less than dt the density $W_t(t) = \lambda$. In this case, when we consider the process in the interval [-T/2, T/2] (which henceforth will be assumed), the uniform distribution $W_t(t)dt$ must be normalized to unity in this interval, that is, $W_t(t) = 1/T$.

We will find the characteristic function $\varphi_\xi(s)$ of the $\xi(t)$ value (with fixed t this is a random value), stipulated in the interval [-T/2, T/2]. (The method for computing the characteristic and correlation functions of the process, differing from (1) only in that pulse amplitude is a random value, not a random process, was described in detail in [8]. Therefore, these computations will be presented here only in summary.) The probability of the event A, involving satisfaction of the inequality $x < \xi(t) \leqslant x + dx$, can be written: $P\{A\} = W_\xi(x)\, dx$, where $W_\xi(x)$ is the probability density distribution for the $\xi(t)$ value. The event A is realized together with one of the events B_n, n = 0, 1,..., forming a full group of mutually exclusive events, where B_n is the appearance of exactly n pulses in the interval [-T/2, T/2]. It is evident that $P\{B_n\} = P_T(n)$. The conditional probability of the event A is $P\{A|B_n\} = W_\xi(x|n)dx$, where $W_\xi(x|n)$ is the conditional density. Using the total probability formula, it is possible to write

$$P\{A\} = \sum_{n=0}^{\infty} P\{B_n\} P\{A\,|\,B_n\} = W_\xi(x)\, dx = \sum_{n=0}^{\infty} P_T(n)\, W_\xi(x\,|\,n)\, dx. \tag{3}$$

By averaging the $\exp(is\xi)$ value using the probability (3), we obtain the characteristic function

$$\varphi_\xi(s) = \sum_{n=0}^{\infty} P_T(n)\,\varphi_\xi(s\,|\,n), \tag{4}$$

where $\varphi_\xi(s|n)$ is the characteristic function of the value

$$\xi_n(t) = \sum_{i=1}^{n} F_i(i).$$

By virtue of the fourth hypothesis all F_i are statistically independent and their probability distributions are not dependent on the i number. Accordingly, it is possible to write

$$\varphi_\xi(s\,|\,n) = [\varphi_F(s)]^n, \tag{5}$$

where the characteristic function of the F(t) value has the form

$$\varphi_F(s) = \int_{-\infty}^{\infty} W_u(u)\,du \int_0^{\infty} W_\theta(\theta)\,d\theta \int_{-T/2}^{T/2} \exp\left\{isu(t)\,I\left(\frac{t-\tau}{\theta}\right)\right\} W_t(\tau)\,d\tau. \tag{6}$$

Here $W_u(u)$ and $W_\theta(\theta)$ are the probability density distributions of the u(t) and θ values. In order to obtain a final expression for $\varphi_\xi(s)$ it is necessary to substitute into (6) the uniform density $W_t(t) = 1/T$ and replace the variable $(t - \tau)/\theta = \tau'$. The derived expression is then substituted into (5) and then into (4). After simple transformations we obtain the formula

$$\varphi_\xi(s) = \exp\left\{\lambda \int_{-\infty}^{\infty} W_u(u)\,du \int_0^{\infty} \theta W_\theta(\theta)\,d\theta \int_{-\infty}^{\infty} [e^{isuI(\tau)} - 1]\,d\tau\right\}. \tag{7}$$

(The limits of integration for τ (the index is omitted) are extended to infinity $T\to\infty$, since the integrand is different from zero only within the limits of the pulses, whereas outside the interval [-T/2, T/2] they are absent.)

Using formula (7) it is possible to find the semi-invariants of the distribution. For this we will reduce (7) to logarithmic form, expand the exponent into a series and find the coefficients on $(is)^k/k!$, which also will be semi-invariants $\varkappa_k(\xi)$ of the order k:

$$\varkappa_k(\xi) = \lambda \int_{-\infty}^{\infty} u^k W_u(u)\,du \int_0^{\infty} \theta W_\theta(\theta)\,d\theta \int_{-\infty}^{\infty} I^k(\tau)\,d\tau = \mu\langle u^k\rangle. \tag{8}$$

Here the parameter $\mu = \lambda\theta = \langle n\rangle\langle\theta\rangle/T$ is the mean intermittence coefficient. In the absence of intermittence $\mu = 1$ ($\langle\theta\rangle = T$, $\langle n\rangle = 1$) and $\varkappa_k(\xi) = \langle u^k\rangle = \varkappa_k(u)$ for k = 1, 2, 3. However, for $k > 3$ these semi-invariants coincide, which is probably related to the rigorous conditions imposed on the model. We note that under the condition $\mu = 1$ the developing pulse covers the entire interval [-T/2, T/2] and evidently it includes no external intermittence, but internal intermittence is present, a theoretical description of which was presented in [5-7, 9-11]. With an intensification of intermittence and degeneration of turbulence $\mu\to 0$ ($\langle\theta\rangle\to 0$, $\langle n\rangle\sim$ const) the semi-invariants $\varkappa_k(\xi)\to 0$, as might be expected. It also follows from formula (8) that the semi-invariants $\varkappa_k(\xi)$ are not dependent on time, since u(t) is a stationary random process.

We will find the correlation function $B_\xi(t,\tau) = \langle \xi(t)\xi(t+\tau)\rangle$ (here the term $\langle \xi(t)\rangle^2$ is absent because under the condition $\langle u(t)\rangle = 0$ it follows from expression (8) that: $\varkappa_1(\xi) = \langle \xi(t)\rangle = \langle u(t)\rangle = 0$). Much as formula (3) was derived, it is possible to derive a formula for the probability of the event, involving simultaneous satisfaction of the inequalities $x<\xi(t)\leqslant x+dx$ and $y<\xi(t+\tau)\leqslant y+dy$:

$$W_{\xi,\xi_\tau}(x, y)\,dx\,dy = \sum_{n=0}^{\infty} P_T(n)\,W_{\xi,\xi_\tau}(x, y\,|\,n)\,dx\,dy. \tag{9}$$

Here $W_{\xi,\xi_\tau}(x, y)$ is the two-dimensional probability density of the random values $\xi(t) = \xi = \sum F_i(t)$ and $\xi(t+\tau) = \xi_\tau = \sum_k F_{k,\tau}(t+\tau)$, whereas $W_{\xi,\xi_\tau}(x, y|n)$ is the conditional two-dimensional density. Averaging the product $\xi\xi_\tau$ using the probability (9), we obtain

$$B_\xi(t,\tau) = \sum_{n=0}^{\infty} P_T(u)\,B_\xi(t,\tau\,|\,n), \tag{10}$$

with the conditional correlation function

$$B_\xi(t,\tau\,|\,n) = \sum_{i,k=1}^{n}\langle F_iF_{k,\tau}\rangle = \sum_{i=1}^{n}\langle F_iF_{i,\tau}\rangle + \sum_{i\neq k}\langle F_i\rangle\langle F_{k,\tau}\rangle = \tag{11}$$
$$= n\langle FF_\tau\rangle + (n^2-n)\langle F\rangle^2 = n\langle FF_\tau\rangle.$$

With the transformation of the double sum in (11) we made assumptions concerning the statistical independence of F_i and $F_{k,\tau}$ with $i \neq k$, and also on the nondependence of the distribution of probabilities of the random values F_i on the number i. In addition, $\langle F\rangle = \langle uI\rangle = \langle u\rangle\langle I\rangle = 0$, since $\langle u(t)\rangle = 0$. Then

$$\begin{aligned}\langle FF_\tau\rangle &= \langle uIu_\tau I_\tau\rangle = \langle uu_\tau\rangle\langle II_\tau\rangle = \\ &= B_u(\tau)\int_0^\infty W_\theta(\theta)\,d\theta\int_{-T/2}^{T/2} I\left(\frac{t-t'}{\theta}\right) I\left(\frac{t+\tau-t'}{\theta}\right)\frac{dt'}{T} = \\ &= \frac{B_u(\tau)}{T}\int_0^\infty \theta W_\theta(\theta)\,d\theta\int_{-\infty}^{\infty} I(t'')I\left(t''+\frac{\tau}{\theta}\right)dt'' = \\ &= B_u(\tau)\frac{1}{T}\int_\tau^\infty(\theta-\tau)\,W_\theta(\theta)\,d\theta,\end{aligned} \tag{12}$$

since

$$\int_{-\infty}^{\infty} I(t'')\,I\left(t''+\frac{\tau}{\theta}\right)dt'' = \begin{cases}0, & \theta<\tau \\ 1-\dfrac{\tau}{\theta}, & \theta>\tau\end{cases}.$$

Here $B_u(\tau)$ is the correlation function of the process u(t). Substituting (12) into (11) and (10), we obtain the expression

$$B_\xi(t, \tau) = B_u(\tau) B_I(\tau) = B_\xi(\tau), \quad B_I(\tau) = \lambda \int_\tau^\infty (\theta - \tau) W_\theta(\theta) d\theta, \tag{13}$$

where $B_I(\tau)$ is a dimensionless correlation function satisfying the conditions

$$B_I(0) = \mu, \quad \left.\frac{dB_I(\tau)}{d\tau}\right|_{\tau=0} = -\lambda, \quad B_I(\tau)|_{\tau\to\infty} \to 0 \tag{14}$$

(the first condition also follows from (8) with k = 2). It can be seen from (8) and (13) that the $\xi(t)$ process is stationary, at least in a broad sense, and therefore its energy spectrum is a Fourier transform of the $B_\xi(\tau)$ function.

In order to find the function $B_I(\tau)$ in explicit form it is necessary to stipulate the density $W_\theta(\theta)$ analytically. As the scheme for the evolution of turbulent "spots" we use the process of their independent fragmentation. Then, in accordance with [3], the distribution of probabilities of the sizes of such "spots" should be described by the log-normal function

$$W_\theta(\theta) = \frac{1}{\sqrt{2\pi}\,\sigma_{\ln\theta}\theta} \exp\left\{-\frac{(\ln\theta - m_{\ln\theta})^2}{2\sigma^2_{\ln\theta}}\right\}, \tag{15}$$

where

$$m_{\ln\theta} = \langle \ln\theta \rangle, \quad \sigma^2_{\ln\theta} = \langle (\ln\theta - m_{\ln\theta})^2 \rangle.$$

It must be noted that almost nothing is known about the density $W_\theta(\theta)$ and the distribution (15) can be used only as a hypothesis. (In [1] a system of Pearson distributions was used as an approximation of $W_\theta(\theta)$. The choice of any particular distribution from this system is based on a criterion which in the experimental evaluations of the moments of the distribution of probabilities of the investigated parameter is very approximate. Therefore, apparently for most of the processed records (fluctuations of sea water conductivity) it is possible to obtain a B-distribution of the first kind in a limited range of values, which is not physically justified. Indeed, the very choice of the Pearson system is unsound.) Substituting (15) into (13), we obtain the expression

$$B_I(\tau) = \mu\left[N(x_\tau - \sigma_{\ln\theta}) - \frac{\tau}{\langle\theta\rangle} N(x_\tau)\right], \tag{16}$$

where

$$N(z) = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-r^2/2} dr, \quad x_\tau = (\ln\tau - m_{\ln\theta})/\sigma_{\ln\theta}.$$

In the computations we then used the property of the distribution (15):

$$\langle\theta^k\rangle = \exp(k m_{\ln\theta} + k^2\sigma^2_{\ln\theta}/2)$$

and its corollaries: $m_{\ln\theta} = \ln(\langle\theta\rangle^2/\langle\theta^2\rangle^{1/2})$, and $\sigma^2_{\ln\theta} = \ln(\langle\theta^2\rangle/\langle\theta\rangle^2)$.

The function (16) decreases monotonically with an increase in τ and satisfies the conditions (14). With $\mu = 1$ ($\langle\theta\rangle = T$) the function $B_I(\tau) = (1 - \tau/T)$. With an increase in the length of the processed record ($T \to \infty$) the function $B_I(\tau) \to 1$.

Thus, the correlation function $B_\xi(\tau)$ of the $\xi(t)$ process decreases with an increase in τ more rapidly than the correlation function $B_u(\tau)$ of the u(t) process. In this case the $E_\xi(f)$ spectrum of the $\xi(t)$ process will decrease with an increase in the frequency f more slowly than the spectrum $E_u(f)$ of the process u(t), since in a limiting case a delta-correlated process corresponds to a uniform "white noise" spectrum. Such is the influence of intermittence on the correlation and spectral functions. Unfortunately, it is impossible to obtain the $E_\xi(f)$ spectrum (being the faltung of the spectra $E_u(f)$ and $E_I(f)$)in explicit form and evaluate the influence of the intermittence parameters on the spectral components of the u(t) process in different frequency intervals (scale intervals), since the function $B_u(\tau)$ (or the function $E_u(f)$) is unknown and the Fourier transform of the function (16) is not expressed either in elementary or in special functions and requires numerical calculations on an electronic computer. (The empirical spectra of the fluctuations of hydrophysical fields in the ocean frequently correspond to some theoretical models of turbulence not taking external and internal intermittence into account (for example, see [4]). This is attributable to the fact that in computing the spectra it is customary to select uniform segments of the records of signals in which it is known that external intermittence is absent. Accordingly, the observed power spectra correspond in the model to the case $\mu = 1$ and do not contradict it. However, the influence of internal intermittence on the spectra is negligible.

Now we will evaluate the influence of intermittence on the mean rate of dissipation of turbulent energy $\langle\varepsilon\rangle$. This requires computation of the correlation function of the derivative process $\xi(t)$, that is, the process

$$\dot{\xi}(t) = d\xi(t)/dt = \sum_i \dot{F}_i,$$

where

$$\dot{F}_i = \dot{u}_i I_i + u_i \dot{I}_i/\theta_i, \quad \dot{I}(x) = \delta(x) - \delta(x-1),$$

$\delta(x)$ is a delta function. The computation of the $B_{\dot{\xi}}(\tau)$ function is similar to computation of the $B_\xi(\tau)$ function. Performing all the necessary operations, for $B_{\dot{\xi}}(\tau)$ we obtain the expression $B_{\dot{\xi}}(\tau) = B_{\dot{u}}(\tau)B_I(\tau)$, where $B_{\dot{u}}(\tau)$ is the correlation function of the process $\dot{u}(t)$, $B_I(\tau)$ is the dimensionless function (13). Assume that $\xi(t)$ is a random function of velocity fluctuations along the t coordinate. Then for locally isotropic turbulence $\langle\varepsilon_\xi\rangle = 15\nu\langle(\partial\xi(t)/\partial t)^2\rangle = 15\nu B_{\dot{\xi}}(0)$. Using (13) it is possible to write $\langle\varepsilon_\xi\rangle = \mu\langle\varepsilon_u\rangle$, where $\langle\varepsilon_u\rangle = 15\nu\langle(\partial u/\partial t)^2\rangle$ is dissipation in the absence of intermittence, that is, the measured mean dissipation is proportional to the mean intermittence coefficient, which is physically plausible. It can be shown that the semi-invariants of the distribution of probabilities of the process $\dot{\xi}(t)$ are also proportional to μ.

Thus, in the particular model the semi-invariants are dependent only on the mean intermittence coefficient (as might be expected), whereas the correlation and spectral functions are dependent on the parameter λ and on the distribution of the probabilities of the sizes of the "turbulent spots."

The author expresses appreciation to R. V. Ozmidov for useful discussion of the work.

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VERTICAL VARIABILITY OF SMALL-SCALE OCEAN TURBULENCE

Moscow OKEANOLOGIYA in Russian Vol 20, No 3, 1980 pp 402-407

[Article by V. S. Belyayev, A. N. Gezentsvey and M. M. Lyubimtsev, Institute of Oceanology imeni P. P. Shirshov USSR Academy of Sciences, submitted for publication 25 January 1979, resubmitted after corrections 23 November 1979]

[Text]

Abstract: On the basis of empirical data on fluctuations of velocity and mean temperature obtained in a vertical sounding regime in the Pacific Ocean a study is made of the distribution of probabilities of the current structural functions D(r). It is shown that in layers with a constant vertical temperature gradient dT/dz the D(r) values have a log-normal distribution for shifts of the r function belonging to the buoyancy interval when the spectrum of velocity fluctuations is $E(k) \sim k^{-3}$. In a general case, when dT/dz changes, the D(r) values do not have a log-normal distribution for all shifts.

A distinguishing characteristic of the vertical distribution of the parameters of microstructure of geophysical fields in the ocean is their nonmonotonic change with depth, which is evidently attributable to the variability of local background conditions. An investigation of the interrelationship of turbulence and local background conditions in the ocean has been made in a number of studies [2-4, 13] in which the authors obtained the first interesting results. A further study of this interrelationship is now one of the most important tasks in physical oceanology.

On the 15th voyage of the scientific research ship "Dmitriy Mendeleyev" (1975) in the zone of the south subarctic front in the northwestern part of the Pacific Ocean, in a region with the coordinates 36°20'N and 149°E a microstructure probe was used in sounding the water layer from 100 to 500 m. The interval between soundings was 20 minutes. In this study we analyze synchronous records of the current velocity fluctuations u' and mean temperature T. The characteristics of the probe measurement channels (designed by the Special Design Bureau of Oceanological Equipment (SDB OE) of the Institute of Oceanology USSR Academy of Sciences) are given in [16]. Large-scale background conditions in the measurement region are described in [1] on the basis of data from a standard hydrological station.

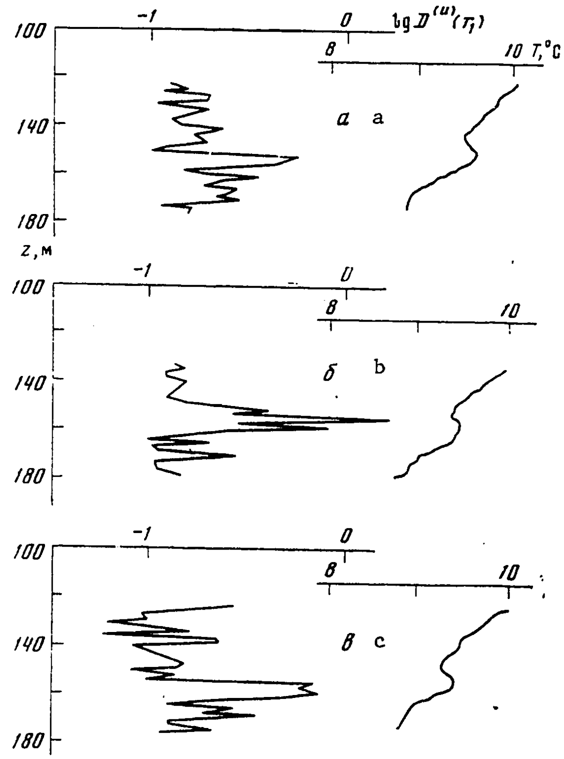

Fig. 1. Segments of profiles with temperature inversion and logarithm of current structural functions for three successive soundings a, b, c.

The current structural functions of the fluctuation signals u' [5] were computed from segments of records with a duration ~1 sec (the corresponding water layer was ~1.7 m) for several spatial shifts r not exceeding 21.8 cm. The values of the current structural functions D(r) with a fixed r vary with depth irregularly; there are "surges" whose magnitude may exceed the adjacent values by an order of magnitude. From a comparison of the D(r) distributions with depth and the corresponding vertical temperature profiles T(z) it follows that in temperature inversion layers there is usually a marked increase in the D(r) values for all r shifts. As an example, Fig. 1 shows segments of T(z) profiles with a clearly expressed temperature inversion for three successive soundings. At the left we show the corresponding lg D (r) distributions of the signal u' for r = 2.7 cm. The temperature profile is appreciably transformed from sounding to sounding; in particular, there is a change in the absolute temperatures in the inversion layer and also its position with depth. This is attributable to both the horizontal variability of the temperature field in the frontal zone and the kinematic effect of internal gravitational waves. If the intensity of turbulence is judged from the D(r) values (since D(r) is the signal dispersion in the "window" of scales, determined by the r shift [6]), in the changing temperature field the turbulence layer increases in the inversion layers. Without having information on the fine structure of the salinity field S in the measurement region it is difficult to express an indisputable judgment concerning the origin of the above-mentioned temperature layer. In all probability the temperature inversion was caused by water advection in the frontal zone. If the intrusion layer is hydrostatically stable, the generation of turbulence in it can occur, for example, due to instability of the vertical velocity gradient.

An increase in the intensity of the microstructure of the temperature field in temperature inversion layers was noted in [17]. The measurements were made 500 km from the shores of Southern California with a free buoy drifting at a depth of 550 m, which simultaneously carried out vertical scanning in the limits of a layer 20 m in thickness. In this case it was possible to detect intrusion layers with vertical extent $\sim$5 m in which there was a marked increase in the values of the small-scale temperature gradient. In the case of intrusion of warm water the greatest intensity of fluctuations of the temperature gradient were observed at the upper and lower boundaries of the intrusion layer. According to [17], the most probable mechanisms of generation of microstructure of the temperature field here are either shear instability or convection as a result of the double diffusion effect. It should be emphasized that the intensity of the microstructure of the temperature field is unambiguously related to the energy of small-scale turbulence. Therefore, the presence (absence) of a microstructure of the temperature field is reliable evidence of the presence (absence) of turbulence and direct measurements of small-scale current velocity fluctuations undoubtedly in this case are of primary importance.

Data from five soundings were used in computing the current structural functions of the signals u' and empirical probability distribution functions for the values ξ_j = lg D (r_j) with r_1 = 2.7 and r_2 = 21.8 cm. The table gives evaluations of the mean value m, standard deviation σ, assymetry coefficient A and excess coefficient E for distributions of the ξ_j values for each sounding (1-5), and also for the total distribution of these values using data for all five soundings. For all the considered ξ_j values the m and σ evaluations are relatively stable, whereas the A and E evaluations have a considerable scatter. This is attributable to individual "surges" of the ξ_j values, which, as noted above, were localized in thin deep layers. The number of such "surges" in each sounding is small in comparison with the volume of the sample and therefore their influence on the distribution of probabilities is clearly manifested only in evaluations of the third and fourth moments (for the total distribution the A and E values are usually less than for individual soundings). The table shows that the distributions of probabilities of the ξ_j values in most cases are asymmetric, whereas the excess coefficients are positive and considerably greater than zero, which is evidence of a strong vertical intermittence of the ξ_j values. This is evidently related to the variability of local background conditions with depth, as is indicated by the vertical temperature profiles T(z), having a clearly expressed fine structure. Using the Kolmogorov-Smirnov test [8], with a significance level 0.1, the hypothesis of a normal distribution of the lg D(r) values cannot be adopted.

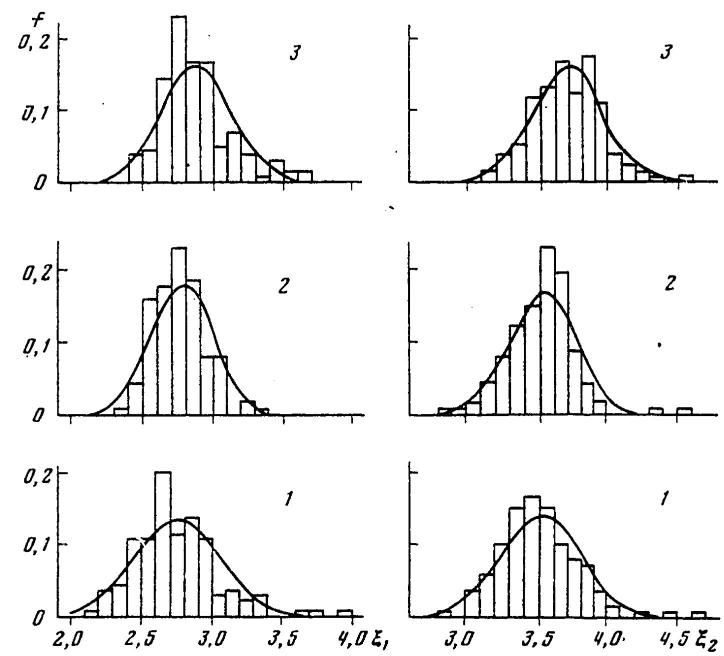

Fig. 2. Histograms of distributions of ξ_1 and ξ_2 values for layers 1, 2, 3.

In order to study the distribution of probabilities of the ξ_j values under conditions of an unvarying background (or varying slightly) we computed the distributions of these values from samples from layers with an approximately constant mean temperature gradient $dT/dz \approx -0.02°C\ m^{-1}$ (layer 1) and $dT/dz \approx -0.01°C\ m^{-1}$ (layer 2), and also from a temperature inversion layer with $dT/dz \approx 0.008°C\ m^{-1}$ (layer 3). The position of the mentioned layers and their thickness, being approximately 50 m, varied from sounding to sounding. The volume of collected samples for layers 1, 2 and 3 was 136, 113 and 139 respectively. A comparison of the empirical distribution functions for different layers was made using the Kolmogorov-Smirnov test with a significance level 0.1. In accordance with this test it is possible to adopt the hypothesis that samples of ξ_j values for layers 1 and 2 belong to the same general set, whereas for layers 1 and 3, 2 and 3 this hypothesis must be refuted. This is evidence that the regime of turbulent movements in layers 1 and 2 is evidently identical, whereas in layer 3 it is essentially different.

Evaluations of Moments of Distributions of Probabilities of Values $\xi_j = \lg D(r_j)$

№ зондирования 1	Количество членов выборки 2	ξ_1				ξ_2			
		m	σ	A	E	m	σ	A	E
1	236	2,26	0.28	1,45	6.66	3,06	0,32	—0,46	2,48
2	231	2,76	0,24	1,84	7,16	3,55	0,26	0,06	0,92
3	231	2,81	0,28	1,10	2,30	3,55	0,27	—0,02	0,74
4	245	2,72	0,30	0,97	2,35	3,50	0,34	—1,06	3,22
5	231	2,72	0,33	1,31	2,90	3,49	0,27	0,56	0,57
3 Всего	1174	2,65	0,35	0,46	1,70	3,43	0,35	—0,55	1,47

KEY:

1. No of sounding
2. Number of terms in sample
3. Total

Figure 2 shows histograms of the distributions of the ξ_1 and ξ_2 values in layers 1, 2 and 3. Here we have also shown curves of the normal distribution law with mean values and dispersions equal to the corresponding empirical evaluations. The hypothesis of a normal distribution of the ξ_1 and ξ_2 values can be adopted for all three layers. Thus, the distribution of probabilities of the current structural functions under some constant background conditions is described by a log-normal law and the parameters of this law are evidently determined by local conditions. An analysis of the distribution moments of the ξ_j values in individual layers shows that the difference in the empirical distributions in layers 1 and 3, 2 and 3 is attributable primarily to a change in the mean value, whereas the dispersion remains virtually constant.

In an investigation of the distribution of probabilities of the current structural functions it must be taken into account to what interval of scales the shift of r functions belongs. For example, it was demonstrated in [7] that if r belongs to the inertial interval then $\lg D(r)$ has a normal distribution of probabilities and differs from it if r belongs to the transitional region of the inertial-dissipative interval of scales. We computed the one-dimensional spectra of velocity fluctuations $E_1(k)$ by the fast Fourier transform method for each of the layers 1-3. In the interval of wave numbers $1.68 \cdot 10^{-1} < k < 2.98$ cm^{-1} (or scales $2.1 < r < 37.4$ cm) the spectra are described by a power function with the exponents $\alpha \approx -3$. The turbulence spectra in the buoyancy interval [9] and the spectra of internal waves have such a form. The author of [11] proposed a test for discriminating the spectra of turbulence and internal waves, according to which the spectrum E(k) is the turbulence spectrum if there is satisfaction of the expression $F(k) = [k^3E(k)]^{1/2} \gtrsim N$. Here E(k) is the three-dimensional isotropic spectrum, N is the Brent-Väisälä frequency. We computed the functions F(k) (use was made of the correlation between E(k) and $E_1(k)$ for a solenoidal isotropic vector field [10]) and the frequency N (according to data from a standard hydrological station and according to the local values dT/dz with a constant salinity value and the maximum N value was used) for each of the layers 1-3. In all cases in the investigated interval of scales there was satisfaction of the expression $F(k) > N$. Thus, the distributions of probabilities of the current structural functions D(r) for the shifts r belonging to the buoyancy interval, with constant local background conditions, in particular, with dT/dz = const, are log-normal and the parameters of the distributions are dependent on background conditions. A log-normal distribution of probabilities for D(r) with r shifts belonging to the inertial interval follows from the refined theory of locally isotropic turbulence [12, 14, 15] and was confirmed experimentally [7]. However, the form of the D(r) distribution with r from the buoyancy interval has still not been theoretically examined. The formulation of such a problem is extremely timely in light of the results obtained above.

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SOUND PROPAGATION VELOCITY IN THE KUROSHIO ANTICYCLONIC EDDY ZONE

Moscow OKEANOLOGIYA in Russian Vol 19, No 3, 1979 pp 381-385

[Article by B. N. Bolgurtsev, Pacific Ocean Higher Marine School imeni S. O. Makarov, submitted for publication 19 May 1978]

[Text]

Abstract: The author has made an analysis of the distribution of the speed of sound in the zone of a mesoscale eddy (40-42°N, 143-146°E) in July 1970. The characteristics of the underwater sound channel and the form of the trajectory of sonic rays at the boundary of the eddy and within it are investigated. The latter exerts a substantial influence on the spatial change in the trajectory of the sonic rays.

At the present time oceanologists are devoting great attention to study of eddylike disturbances in the ocean which have horizontal scales of about 50-110 miles and a lifetime from several days to one year or more and have their own thermohaline structure, determining the vertical distribution of temperature and salinity. Accordingly, each such eddy must also have distinguishing characteristics of sound propagation, that is, there must be a definite hydroacoustic structure which is characterized by the shape of the curve of the vertical distribution of the speed of sound, the type of underwater sound channel (USC) and the values of its parameters. The transition through the boundary of the eddy, where waters with different hydrological structures interact, should be accompanied by a marked change in the conditions for sound propagation.

We know of two studies [4,6] which are devoted to an investigation of sound propagation in the effective zone of the eddies. Both articles examine the acoustic characteristics of the cyclonic "rings" in the Gulf Stream. The results of these studies indicate that there are distinguishing characteristics in the distribution of the speed of sound peculiar to eddies of the Gulf Stream.

In this connection it is of interest to examine the principal characteristics of the propagation of sound through eddies separating from the Kuroshio in the zone of the subarctic front in the northwestern part of the

Pacific Ocean. Such an investigation has not been made for the system of Kuroshio waters, although the region is interesting in both scientific and in practical respects as a region of ocean fishing.

In the region of contact between the waters of the Kuroshio and Oyashio there are two types of eddies: anticyclonic (or warm), moving for the most part to the north and northeast, and cyclonic (or cold), moving to the south and southwest. The anticyclonic eddies extend to a great depth (500-600 m). The principal regions of their formation are situated between 141 and 145°E in the zone 33-38°N [1]. Cyclonic eddies are formed along the southern shore of Honshu between 135° and 140°E, 145-148° E and 33-36°N and extend to a depth of 400-500 m [1]. The Kuroshio eddies have a circular or elliptical shape with a diameter from 60 to 200 miles. The spatial rate of movement varies from a half-mile to four miles per day. Their lifetime is approximately a half-year to a year and is dependent on many factors (conditions for interaction with cold waters of the Oyashio, degree of development of atmospheric processes, current velocities at the surface, etc.).

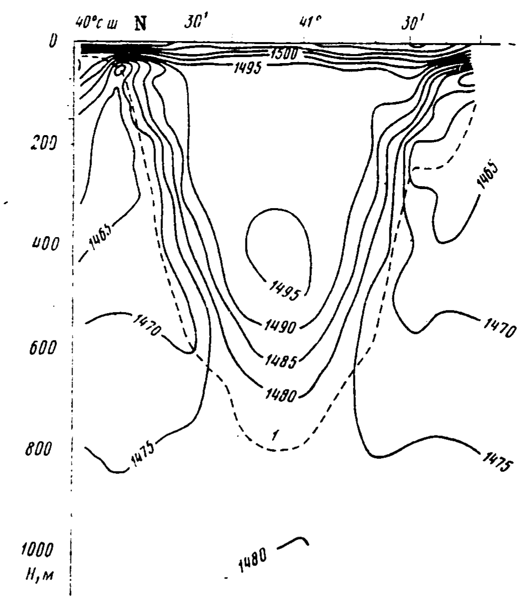

Fig. 1. Vertical section of the speed of sound field along 145°E. 1) axis of underwater sound channel.

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As the initial data for the analysis of conditions for sound propagation in the eddy zone we used standard observations of temperature and salinity made by Japanese researchers during the lifetime of a warm eddy (February 1970 - October 1971) [5]. On the basis of these data and the Wilson formula (1960), using the data in [2], we computed the speed of sound field for the region 40-42°N and 143-146°E.

During the time of observations the eddy moved to the northeast for a distance of 400 miles. In July 1970 it had the following parameters: radius about 45 miles, vertical thickness 700 m, velocity of movement 0.75 mile daily. Its center was situated at a point with the coordinates 40°55'N, 145°02'E. Along the contour of the eddy there was a sharply expressed temperature front with a gradient up to 0.27° per mile at the ocean surface and more than 0.5° per mile at a depth of 50-125 m.

The complex distribution of thermohaline characteristics in the region of the eddy causes an equally complex distribution of the speed of sound. Figure 1 shows the vertical section of the speed of sound field along 145° E for the period 23-24 July 1970 and passing through the center of the eddy. It can be seen that in the upper 40-m water layer the speed of sound varies from 1,495 to 1,520 $m \cdot sec^{-1}$. The greatest vertical gradients here exceed 0.7 $m \cdot sec^{-1}$ per meter (maximum 0.95 $m \cdot sec^{-1}$ per meter) and are observed primarily in the layer 10-30 m. Below the seasonal sonic tachocline the mesoscale eddy at its boundaries is characterized by considerable horizontal gradients which on the average are 1.64 $m \cdot sec^{-1}$ per mile (see table).

Horizontal Speed of Sound Gradients at Boundaries of Mesoscale Eddy

Horizon, m	Horizontal gradients, $m \cdot sec^{-1}$/mile	
	maximum	minimum
50	4.67	1.25
100	3.12	0.52
200	2.51	0.81
300	2.51	0.52
400	2.49	0.25
500	2.00	0.35
600	1.20	0.70

In the central part of the eddy the change in the speed of sound does not exceed 5 $m \cdot sec^{-1}$.

In order to solve different kinds of practical problems (search for schools of fish, fishery forecasts, etc.) it is of great importance to determine the anticipated effective range of hydroacoustic instruments (HAI), dependent on the spatial-temporal variability of the speed of sound field. A factor of interest is the position of the speed of sound minimum or the depth of the USC axis. It is well known that if the sound source is situated on the USC axis the effective range of the USC can increase greatly.

In Figure 1 it is easy to trace the distorting effect of the eddy on the depth of the horizon, where the speed of sound has a minimum value. For example, on the outer side of the eddy the USC axis is situated closer to the surface at depths of 50-250 m. This agrees, in general, with the values cited in [3]. At the boundary of the eddy it drops downward sharply and at the center lies approximately at the horizon 800 m. Accordingly, the speed of sound on the USC axis increases from 1,461-1,463 to 1,476-1,478 $m \cdot sec^{-1}$. Thus, the USC region in the eddy zone is far from stability and homogeneity and this undoubtedly is reflected in the reliability of the predicted effective range of HAI.

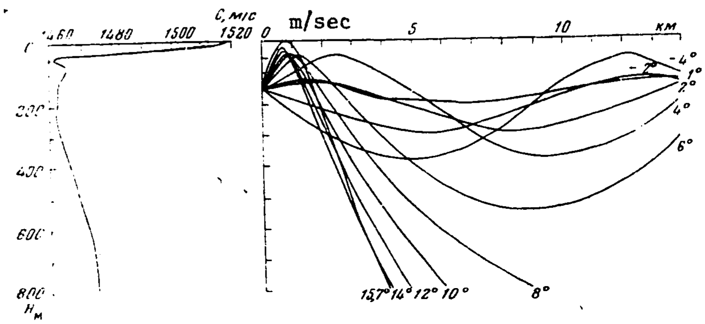

Fig. 2. Trajectories of rays on boundary of eddy.

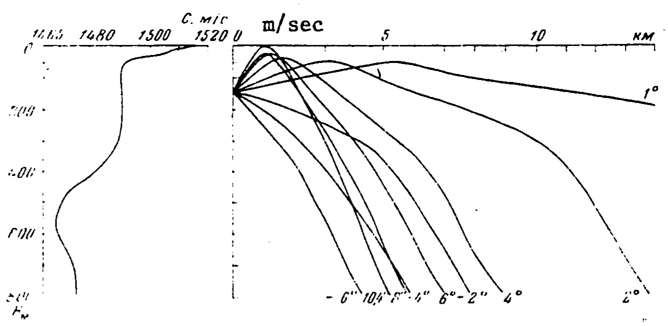

Fig. 3. Trajectories of rays within eddy.

Accordingly, in practical computations great care must be exerted in selecting the characteristic profile of the curve of vertical distribution of the speed of sound in regions which in their geometric dimensions are commensurable with the mean diameter of the mesoscale eddy (50-110 miles). The curve reflecting some special situation is especially limited in time. Therefore, in open regions of the oceans it is desirable that measurements of the vertical distribution of water or the speed of sound to a depth of 400-500 m be made each 4-6 hours, and in the zone of the probable existence of mesoscale eddies and hydrological fronts this interval must evidently be reduced still more.

We note that in [7], for the purposes of routine prediction, in describing the variability of the USC it is recommended that observations be made to depths of about 200 m at the five main horizons. In our case, for the reasons mentioned above, this probably does not ensure the required accuracy in obtaining the curve of the vertical distribution of the speed of sound and accordingly, a proper evaluation of the effective range of HAI.

The influence of a mesoscale eddy on the propagation of sound oscillations can also be characterized by a spatial variability of the form of the trajectory of sonic rays, as is illustrated graphically using ray patterns for two different cases of the vertical profile of the speed of sound distribution curve. Figures 2 and 3 show the families of rays which we computed for a sound source situated at the horizon 150 m and accordingly situated on the southern boundary of the eddy and within it. In both cases the distribution of the speed of sound with depth along the trajectory, directed toward the center of the eddy, was assumed to be constant (which corresponds to the ray theory).

At the boundary of the eddy (Fig. 2) an exceptionally strong refraction of the rays in the upper part of the subsurface sound channel was caused by a sharp change in the speed of sound with depth (almost 60 $m \cdot sec^{-1}$ at 50 m). As a result, the subsurface UCS takes in a relatively high percentage of the rays, although the sound source is situated at a relatively shallow depth. This is particularly clearly expressed in the rays emanating from the source at angles $\pm 4°$. The geometric range at the source horizon (the distance along the horizontal from the sound source to the boundary of the first shadow zone) is about 4.9 km.

Within the eddy (Fig. 3), as a result of negative refraction in the layer 0-75 m, the speed of sound first decreases to 1,490 $m \cdot sec^{-1}$ and then almost remains constant to the 300-m horizon. Then it again decreases to the axis of the deep USC (horizon 600 m). The zone of the acoustic shadow occupies here a layer which is considerably less than in Fig. 2 and the geometric range increases to 11 km, that is, more than doubles.

Thus, the well-expressed acoustic uniformity of the eddy at depths from 75 to 300 m exerts a substantial influence on the spatial change in the trajectory of the sonic rays and considerably increases the effective geometric range of the HAI.

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[8144/1750-5303]

5303
CSO: 8144/1750

BOOK EXPLORES USES OF THE INTERNATIONAL OCEAN FLOOR

Moscow MEZHDUNARODNYY RAYON DNA MIROVOGO OKEANA (The International Zone of the World Ocean Floor) in Russian 1980 signed to press 8 Jan 80 pp 2-6, 263-265, 278-280

[Annotation, Table of Contents, Foreword, and Conclusion from book by K. A. Bekyashev, L. L. Lyubimov, I. M. Mogilevkin, V. A. Romanov, D. G. Tonkonogov, N. V. Shaskol'skiy, S. G. Shlykov, and I. I. Yakovlev, Izdatel'stvo "Nauka", 1,100 copies, 280 pages]

[Text] Annotation

This work examines the economic, political, and legal aspects of using seabed territory beyond the limits of the continental shelf and exploiting the mineral resources of the international zone of the World Ocean floor, and it analyzes the fundamental principles of the zone's international regime.

Table of Contents — Page

Part Three
The International Agency for Seabed Resources

Foreword

In the last three decades, scientific and technical progress has created significant prerequisites for accelerated inclusion of the resources and spaces of the World Ocean into the world's economic turnover. The world economy's demand for uninterrupted conveyance of tremendous masses of commodities led to enormous growth of commercial shipping. A significant change occurred in the scale of the activities of expeditionary fleets, which increased their annual oceanic catch of biological resources to almost 70 million tons. Marine mining industry developed the mineral resources of the continental shelves with increasing success. The scientific research fleet grew at a fast pace.

As activities in the World Ocean increased in their intensity, the need for improving regulation of such activities at all levels--national, regional, global--came to be felt more and more. International law of the sea occupies a special place in this regard. The Soviet Union and other socialist countries have always attached great significance to progressive and democratic development of the law of the sea. It is precisely this sort of development that could promote wide international cooperation in the World Ocean in the interest of all countries, and insure sensible economic use of marine resources and spaces, and effective protection of the marine environment.

The UN, which has been making a great contribution to improving international legal rules since the 1950's, is called upon to play the most important role in this process. The principal phases of its activity in this area were the UN conferences on the law of the sea. A number of international conventions, to include those dealing with the high seas and the continental shelf, were adopted in the course of the first and second conferences (1958 and 1960, Geneva). On the whole these conventions, despite significant shortcomings in some of them, were a substantial foundation for regulation of the activities of states in the World Ocean. Their regulatory action was extended to practically all forms of marine activities and sea spaces.

Nevertheless a number of factors produced the need, just a decade following the Geneva conferences, for undertaking further steps to improve international law of the sea. One of the main tasks of the new stage in its development was definition of the principles of developing mineral resources of the seabed beyond the limits of the continental shelf. Some aspects of this problem, new to all mankind, have already been reflected in Soviet scientific literature.* However, integrated analysis of this problem is attempted for the first time in the present work.

The issues of regulating exploration and exploitation of deepsea mineral resources were posed about a decade ago. Since that time our knowledge of these resources, their reserves, their distribution, and the mining and processing methods increased significantly. Several drafts of the legal regime for using these resources arose as well. This issue was included in the agenda of the Third UN Conference on the Law of the Sea, the first session of which was held in 1973.

The Third Conference had the purpose of developing a single universal convention on the law of the sea that would regulate all forms of economic activity in different spaces of the World OCean. The conference assigned the work of creating the regime of using mineral resources of the deepsea seabed to its First Committee. Four variants of an unofficial draft of the convention, to include a draft of the regime of exploitation of mineral resources in the international zone of the seabed**--that is, seabed beyond the limits of the continental shelf--were successively written and discussed in the course of seven working sessions of the conference.

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* Kalinkin, G. F., and Ostrovskiy, Ya. A., "Morskoye dno: komu ono prinadlezhit?" [The Seabed: To Whom Does It Belong?], Moscow, 1970; "Okean, tekhnika, pravo" [Ocean, Technology, Law], Moscow, 1972; Kolodkin, A. L., "Mirovoy okean" [The World Ocean], Moscow, 1973; "Mezhdunarodnoye morskoye pravo. Rezhim vod i dna Mirovogo okeana" [International Law of the Sea. The Regime of the Waters and Floor of the World Ocean], Moscow, 1974, pp 256-286.

** For the sake of brevity, the international zone of the seabed will subsequently be referred to as the zone, as is adopted in UN documents.

In essence this was the first time mankind encountered the problem of creating an international universal organization having broad regulatory powers and being endowed with the right to engage in economic activities. Such an organization, which interprets mineral resources of the deepsea floor as "the common heritage of mankind", available for use by all countries, will maintain surveillance over exploitation of these resources. The prinicples governing the activities of this organization and its structure have been under development for many years already. About 150 countries are taking part in this work. Their interests are sometimes deeply divergent in regard to this issue. Nevertheless agreement has been achieved on many provisions of the international regime in recent years. However, a number of provisions still remain unregulated.

This work analyzes world industry's demand for different forms of minerals contained within the zone, and the technical possibilities for their mining and processing. The technical-economic prospects of deepsea development of ferromanganese nodule deposits are assessed. The history of arisal of questions associated with the international regime governing exploitation of the zone's resources and the history of this regime's development are traced, and the interest and positions taken by participants of the conference during development of the fundamental principles of the international regime are assessed. The system for exploring and exploiting the zone's resources, the structure of the International Seabed Agency (subsequently referred to as the agency), and the mechanism for resolving disputes in connection with the use and interpretation of the regime's provisions are analyzed.

Naturally the authors of this study make no claim as to the completeness of the complex problems making up the international regime. It may be said with certainty that work on these problems will be continued in the future by both Soviet and foreign scientists, especially with a consideration for future experience in operation of the international regime. The authors fully recognize that many of the issues examined here may and will elicit different interpretations and approaches. This is unavoidable in the study of any new phenomenon. However, such an analysis affords a possibility for understanding this phenomenon more deeply and for revealing the laws governing its arisal and development. It is precisely in this, in an attempt to broadly and integrally analyze the political and economic principles governing the operation of a viable, mutually acceptable international regime--that the authors of this study saw their principal task.

Conclusion

Created in the course of the Third UN Conference on the Law of the Sea, the international regime of the zone of the World Ocean floor beyond the limits of the continental shelf contains many mutually acceptable provisions today. At the same time some of its elements still generate disagreement, failing to take account of the legal interests of one group of countries or another. The possibility is not excluded that in the course of subsequent negotiations we will be able to achieve a compromise in the regulatory provisions which would bring us closer to a consensus on the international regime as a whole. Examples of such an approach (consent to include provisions in a treaty which do not correspond fully with national interests) are often encountered in the international practice of preparing complex conventions dealing with many problems, when negotiations involve a package of issues and are conducted on the basis of a package approach. In this case concessions in relation to some issues of the package are permitted such that a positive decision could be made on some other issues. The international regime of the zone is also being written within the framework of a single convention on the law of the sea, and it is one of the elements of this package (though it is an extremely important and complex one).

Nevertheless it would have been most proper to define all provisions of the international regime of the zone on a balanced, mutually acceptable basis. After all, this regime is unique in many ways. This is the first time an international universal seabed organization will be created with such far-reaching powers.

Its decisions will predetermine the policies in relation to the international zone of the ocean floor, and it will govern cooperation among states in development of its resources.

This organization will perform independent economic activity. To a certain extent, in view of the present level of science and technology the object of this activity is for the moment inconclusively defined. Out of the entire possible diversity of mineral resources within the zone, in the next few decades the only object of its activity will be ferromanganese nodules, the mining and processing of which are treated in many concrete provisions of the international regime. Naturally, such provisions were written on the basis of available, partial, far from complete knowledge of the zone and its resources. Thus the international regime will operate with some ambiguous provisions.

At the same time it is important to insure true recognition of the fundamental elements of the regime by all countries and groups of countries, since it is aimed at strengthening international cooperation. This pertains especially to fundamental principles of the international regime such as the provision that the region and its resources are available for use to all states exclusively for peaceful purposes, the provision of inadmissibility of territorial claims, the principle of prohibition of monopolies, the principle of nondiscrimination and observance of equal rights of sovereign states, the principle of protecting the marine environment, and the principle of maintaining freedom of the high seas.

The uniqueness of the future international regime of the zone is predetermined by the need for constantly studying all of its elements further and, after the regime goes into effect, the need for meticulously analyzing its results and for preparing recommendations concerning the policy of the agency, a policy which would have the goal of protecting the interests of all countries without exception, and of the present and future generations of mankind. Only such a policy, based on truly equitable cooperation between nations in the development of the zone's mineral resources, can insure the agency's viability, avert seizure of the seabed's resources and their plunder by a narrow group of monopolies, and permit effective activity by the council assembly as well as the agency's secretariat and auxiliary subdivisions.

Work on the zone's international regime is not yet finished. The nations of the entire world are hopefully anticipating that this important process will come to its conclusion as a result of full consideration of the interests of all countries, irrespective of their socioeconomic system, geographic location, or degree of economic development. Extensive and equitable international cooperation in development of the resources of the zone for the good of all mankind is suggested as an alternative to carving up the tremendous spaces and resources of the zone. This alternative is entirely possible, assuming that in relation to all of the basic issues of the zone's international regime, we complete the task posed by our party in relation to all "vitally important problems facing mankind as a whole today", and mainly the task of finding, for these problems, "a sensible collective solution, arrived at through planned international cooperation."* Implementation of this alternative may serve as the most important factor for reinforcing peace and security at sea, and developing relaxation of tension, peaceful coexistence, and cooperation among nations.

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* Brezhnev, L. I., "Leninskim kursom. Rechi i stat'i" [Following Lenin's Course. Speeches and Articles], Moscow, Vol 6, 1978, p 597.

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ARCTIC AND ANTARCTIC RESEARCH

INTERPRETING RADAR IMAGES OF SEA ICE USING AN ELECTRONIC COMPUTER

Leningrad TRUDY GLAVNOY GEOFIZICHESKOY OBSERVATORII: APPARATURA I METODY METEOROLOGICHESKIKH IZMERENIY in Russian No 433, 1979 pp 130-135

[Article by V. Yu. Aleksandrov and V. S. Loshchilov]

[Text] At the present time the method of a radar aerial survey of the ice cover has come into wide use in arctic and middle-latitude freezing seas. The purpose is the routine support of navigation [1, 2]. Radar photographs, although inferior to aerial photographs with respect to resolution, differ from them advantageously in that they can be obtained regardless of meteorological conditions and at any time of day. The difficulties in the visual interpretation process and the great volume of collected information make it necessary to develop methods for the computer interpretation of radar photographs.

In this article we set forth some results of investigations in this direction, in particular, an algorithm making it possible to carry out computer interpretation, as well as the results of its experimental checking. The formulated algorithm makes it possible to classify ice of different age and condition on the basis of the image on a radar photograph, assigning such ice to one of the following classes: 1) water, 2) gray-white ice, 3) white ice, 4) one-year ice, 5) ground and hummocked one-year ice, 6) one-year ice with inclusions of old ice, 7) polar ice.

The algorithm involves the following:

1) for each of the types of ice enumerated above there is selection of a standard image area in which the image optical density values are measured and their histogram is computed;

2) the optical density values are measured on a photograph with an unknown type of ice and their histogram is computed;

3) the resulting histogram is compared with the standard. The determined type of ice is assigned to that class whose measure of closeness to the standard histogram is minimum.

We also carried out investigations of the dependence of the probability of correct identification on the number of quantization levels and the type of closeness measure. Three types of closeness were selected [3]:

1) Kolmogorov variation distance

$$K_{mn}=\frac{1}{2}\sum_{j=1}^{T}|P_m(z_j)-P_n(z_j)|,$$

where $P_m(z_j)$ and $P_n(z_j)$ are the values of the histograms at the points z_j;

2) Bhattacharya distance

$$B_{mn}=-\log\rho_{mn},$$

$$\rho_{mn}=\sum_{j=1}^{T}[P_m(z_j)P_n(z_j)]^{1/2};$$

3) Matusita distance

$$D_{mn}=\left[\sum_{j=1}^{T}\left(\sqrt{P_m(z_j)}-\sqrt{P_n(z_j)}\right)^2\right]^{1/2}.$$

Table 1

Dependence of Probability of Proper Identification on Type of Closeness Measure and Number of Histogram Quantization Levels

Distance	Number of levels				
	42	21	11	6	3
Kolmogorov	0.6	0.7	0.7	0.7	0.3
Bhattacharya	0.6	0.5	0.5	0.3	0.2
Matusita	0.6	0.6	0.7	0.6	0.4

The results of the investigations are given in Table 1. On the basis of the data cited here, and also the data obtained as a result of additional investigations, as the closeness measure we selected the Kolmogorov distance and a number of histogram quantization levels equal to 16. It can be noted that the number of half-tone gradations falling in the radar image is approximately the same. A "Neva" phototelegraphic apparatus was used for the input of photographs into the electronic computer. It was used for introducing standard sectors into the computer and for computing histograms of their optical densities D (Fig. 1).

In checking this algorithm the computer was fed 63 records each of one-year ice, polar ice and one-year ice with inclusions of old ice. Among these 61 of the cases of polar ice were identified correctly and 45 cases each for polar ice and one-year ice with inclusions of old ice. The evaluation for the pronability of correct identification gives

$$\hat{p}=N_{cor}/N_{total}=151/189\approx 0.8.$$

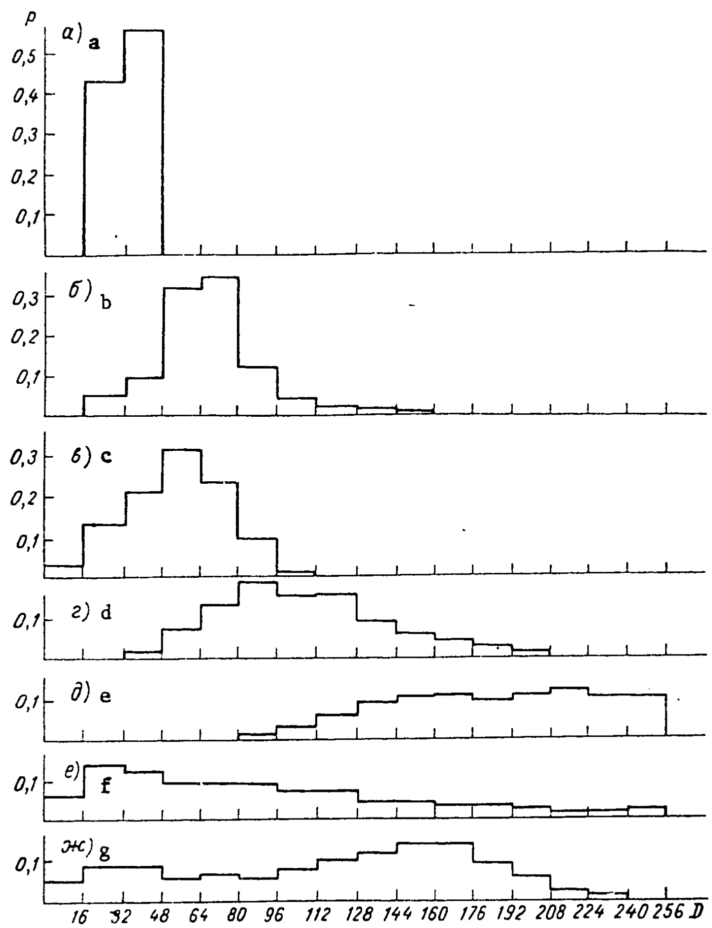

Fig. 1. Histograms of distribution of optical densities for standard sectors. a) water; b) gray-white ice; c) white ice; d) one-year ice; e) one-year ice with predominance of ground and hummocked ice; f) one-year ice with inclusion of old ice; g) polar ice.

The $\hat{p}$ values make it possible to make an evaluation of the true level of error of the classifier. If the true but unknown level of error of the classifier is equal to p and if the classification k of n independent, randomly taken control samples is incorrect, then the k distribution is binomial:

$$P(k) = \binom{n}{k} p^k (1-p)^{n-k}.$$

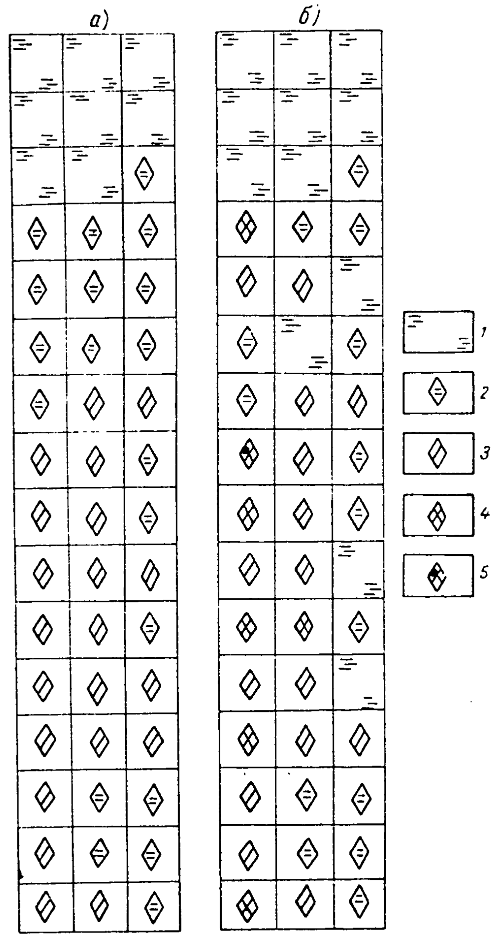

Fig. 2. Age of ice determined by visual interpretation (a) and using an electronic computer (b). 1) water; 2) gray-white ice; 3) white ice; 4) one-year ice; 5) one-year ice with inclusions of old ice.

It follows from the properties of the evaluation for the parameter p of the binomial distribution that the probability that p falls in the interval 0.75-0.85 is equal to 0.95. True, it must be taken into account that the evaluation was made for specially selected sectors. Accordingly, in working with mass material this probability, evidently, will be somewhat less.

Now we will examine the results of interpretation of two photographs. The first (Fig. 2) shows water, gray-white and white ice. The second (Fig. 3) shows polar and one-year ice. The interpretation was made for areas measuring 14 x 14 mm. The optical density values measured from one of the lines in a particular sector were used in identifying the type of ice in the particular sector. It can be seen from an examination of the results of interpretation of the photograph in Fig. 2 that 35 of the 48 sectors were correctly identified, that is, the percentage of correct identification was

$$P = 35/48 \cdot 100 = 73\%.$$

Among the 13 errors made in the classification process 5 were serious, when ice breccia of gray-white and white ice was taken for inclusions of old ice in one-year (1 case) ice or expanses of open water. In the remaining eight cases gray-white and white ice was taken for one-year ice.

In the interpretation of the photograph shown conventionally in Fig. 3 the percentage of correct identification was

$$P = 10/16 \cdot 100 \approx 62.5\%.$$

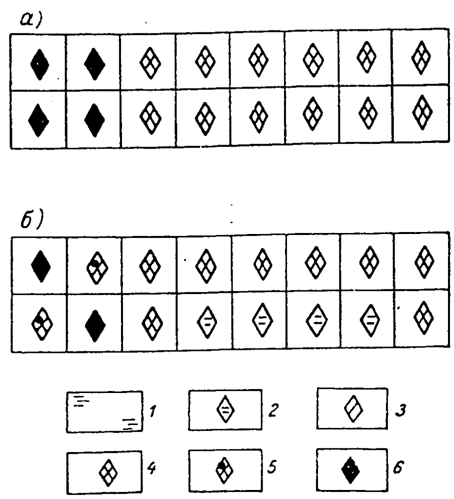

Fig. 3. Age of ice determined by visual interpretation (a) and using an electronic computer (b). Symbols 1-5: see Fig. 2; 6) polar ice.

Despite the rather low percentage, there were no serious errors. All the errors were as follows: polar ice was taken for the inclusion of old ice in one-year ice, whereas one-year ice was taken for gray-white and white ice, and in general, as a result of interpretation the boundary between o'd and young types of ice was detected clearly.

Thus, the collected data show:
1) it is possible to carry out interpretation of radar images of sea ice using the algorithm described above;
2) in assigning an unknown type of ice to one of the classes, as the closeness measure among the considered distances it is best to use the Kolmogorov variation distance;
3) there is an optimum number of levels for quantization of the histogram corresponding to the greatest probability of a correct identification; this number approximately coincides with the number of half-tone gradations falling in the radar photograph.

It must be noted that the considered method can be used in the interpretation not only of radar images of sea ice, but also for aerial photographs, thermal photographs, etc. The percentage of correct identification in this case will be dependent on the potential interpretability of the images themselves. The field of applicability of the method need not be limited to the ice alone. It can be used in the interpretation of images of the sea surface, determination of the type of clouds or soil.

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COLLECTION OF ARTICLES ON HIGH-LATITUDE GEOPHYSICAL RESEARCH

Apatity VYSOKOSHIROTNYYE GEOFIZICHESKIYE ISSLEDOVANIYA VO VREMYA EKSPERIMENTA "GEOS" (REZUL'TATY MIM) (High-Latitude Geophysical Research During the "GEOS" Experiment-Results of the International Magnetic Interval) in Russian 1979 signed to press 25 Dec 79, pp 2, 78

[Annotation and Table of Contents from collection of articles edited by Doctor of Physical and Mathematical Sciences O. M. Raspopov (Responsible Editor), Izdatel'stvo Kol'skogo Filiala im. S. M. Kirova AN SSSR, 350 copies, 82 pages]

[Text] Annotation

This collection of articles is devoted to an investigation of geophysical disturbances in the polar ionosphere during the period of the special international interval from 1 to 15 December 1977. A detailed description of magnetic variations and ionospheric disturbances is given for this period. The change in the level of the superlong-wave signal during the time of the substorm of 1 December was investigated. It is shown that in the presence of strong disturbances in the morning hours there can be a flow of plasma from the daytime cusp to the latitudes of the Fritz zone. In addition, the collection of articles also examines the latitudinal distributions of geomagnetic pulsations and riometer absorption, the influence of the velocity of the solar wind on the course of an auroral substorm and some other problems in high-latitude geophysics. The collection of articles is intended for scientific specialists, graduate students and other students specializing in the field of solar-terrestrial physics and physics of the magnetosphere and ionosphere.

TABLE OF CONTENTS

[16-5303]

5303 -END-
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